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SELECTING SPECIES FOR MARINE ASSESSMENT OF RADIONUCLIDES AROUND AMCHITKA: PLANNING FOR DIVERSE GOALS AND INTERESTS

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Abstract. Considerable attention has been devoted to selecting bioindicator species as part of monitoring programs for exposure and effects from contaminants in the environment. Yet the rationale for selection of bioindicators is often literature-based, rather than developed with a firm site-specific base of data on contaminant levels in a diverse range of organisms at different trophic levels in the same ecosystem. We suggest that this latter step is an important phase in the environmental assessment process that is often missing. In this paper we address the problem of how to select a wide range of species representing different trophic levels that serve as a basis for selecting a few species suitable as bioindicators. We illustrate this with our assessment of radionuclides on Amchitka Island, Alaska. We propose a multi-stage process for arriving at the list of available species that includes review of literature, review by experts experienced in the area, review by interested and affected parties, selection of trophic levels or groups for analysis, arraying of possible species, and selection of species within each trophic level group for sample collection. We first had to identify all likely species, then narrow our focus to those we could collect and analyze. In all cases, review includes suggestions for possible target species with justifications. While this method increases the up-front costs of developing bioindicators for an ecosystem, it has the advantage of providing information for selection of species that will be most informative in the long run, including those that are the best bioaccumulators, thus providing the earliest warning of any potential environmental consequences. Further, the recognition that a range of stakeholder's needs and interests should be included increases the utility for public-policy makers, and the potential for continued usage to establish long-term trends.

Keywords: assessment, marine, bioindicators, radionuclides, stakeholder, regulators, trophic groups, biological diversity

1. Introduction

A wide range of people and agencies are interested in assessing the well-being and health of humans and the environment, including public policy makers, scientists and health professionals, Tribal Nations, conservation agencies, and the general public. This interest has led to the establishment of local, state and federal agencies, as well as environmental/conservation societies to preserve, protect, and manage our environments, and their ecological resources. While there are several paradigms to assess human and ecological health, risk assessment has emerged as the major paradigm embodying the disciplines of toxicology and exposure assessment (NRC, 1983, 1993). Formal risk assessment, however, is often used for a specific stressor or contamination problem, and is applied at a particular point in time. Along with risk assessment, agencies need to continue the assessment process, to understand changes in species or ecosystem function, to evaluate management or remediation actions, and to ascertain that species and ecosystem are still protected. The NRC reports also noted, as had others, that research, validation and monitoring were critical aspects of science that should impact all phases of risk assessment and risk management (NRC, 1993).

Periodic monitoring of "indicators" has emerged as the method of assessing trends and for providing early warning of potential effects from contaminants. Data can be obtained from many sources, involving many abiotic and biotic systems, at a variety of spatial and temporal scales. Ideally, indicator selection and monitoring data are tailored to meet the needs of a particular question or situation, and can provide early warning of any changes that could result in significant risk to humans or ecosystems. Non-biotic indicators include, for example, water or soil monitoring, while bioindicators include measurement of contaminants in tissues, reproductive success, or other measurable endpoints. The value of biomonitoring is enhanced with biomarkers of both exposure and effects in suitable indicator species. Since it is not possible to monitor all species, interactions, and functions of ecosystems, the development of bioindicators and biomarkers has emerged as a critical process (Piotrowski, 1985; Peakall, 1992; Burger and Gochfeld, 2001a, 2004; Carignan and Villard, 2001). Most books devoted to ecological risk assessment provide methods for evaluation at different levels of ecological organization, but do not provide a comprehensive plan for any one habitat or land type, although some have provided plans for regions (Hunsaker *et al.*, 1990; Suter, 1990; Cairns, 1990). Excellent methods are available (Linthurst *et al.*, 1995), but authors seldom discuss the process of obtaining the necessary data to select among potential bioindicators.

There are several features that make some species more useful bioindicators than others, including abundance and accessibility on the one hand or being long-lived, top level predators, inhabiting sensitive habitats with rapid transport of contaminants on the other (e.g. aquatic systems; Burger and Gochfeld, 2001a; Burger, 2000, 2006). Yet, these attributes are seldom fully realized, because in most cases, only one or a very few species are ever examined. Usually bioindicator species are selected based on those described in the literature, or on their status as producers or top-level predators of interest. There are very few studies where more than one or two species serve as bioindicators for contaminants of interest; it is an assumption that these species are the best bioindicators. Yet, only with data from a series of organisms within the same ecosystem can differences among species be evaluated to select the most useful species to be used as bioindicators for monitoring status and trends. Furthermore, not all organisms within an ecosystem can be evaluated, and some selection from the hundreds of species present in an ecosystem is essential.

The selection phase, however, is rarely studied or described. Yet, this is a critical step, particularly for situations where long-term monitoring is part of a stewardship program for a contaminated site. Thus, we propose that bioindicator selection is a two-step process: (1) selection of a broad suite of potential bioindicators, with acquisition of contaminants information on all these species, and (2) selection of bioindicators from this suite. Both steps require extensive literature review, stakeholder input, and scientific evaluation. It is the first step that is seldom performed.

Herein we describe the process we used for selecting among the wide array of potential organisms within marine systems for screening as possible bioindicators of radioactivity at Amchitka. We do not propose that the species we selected will be the most suitable in other places, but we describe the general methods used to select the suite of organisms that could serve as the base for the final selection of bioindicators, using a case study. Once data are available on the contaminants of interest in this wide array of species, it may be a straight-forward matter to select which set of organisms should serve as bioindicators, depending upon assessment needs, endpoints (human, other ecological receptors of interest), and cost and time constraints.

We use Amchitka Island as a case study. Amchitka Island was the site of three underground nuclear tests from 1965–1971. The Department of Energy (DOE) is responsible for any residual radionuclide contamination from the underground nuclear tests, and must develop a long-term stewardship plan to detect radionuclide seepage from the underground test cavities into the marine environment. This could include ascertaining that subsistence and commercial seafoods are safe and that the marine ecosystem is not adversely impacted. But the trends data base could also provide information that suggests that there is seepage, and measures should be taken to reduce possible exposure of subsistence peoples.

This paper is part of a multi-year, multi-disciplinary, multi-university project conducted by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) to determine whether the seafoods around Amchitka Island are currently safe for human consumption, to determine whether marine biota have been exposed to radionuclide levels that might cause significant harm, to provide information that could aid in bioindicator selection for future monitoring, and to reduce uncertainties in the DOE's screening health risk assessments and groundwater models (DOE, 2002a,b).

A wide range of stakeholders have been involved in the design and execution of the research from the start of the project. In other places we describe the process of arriving at a consensus Science Plan (Burger *et al.*, 2005, 2006) and stakeholder involvement in research refinement and execution (Burger *et al.*, ms). This paper deals with the methods used to arrive at the preliminary list of available species to collect for radiological analysis, from which bioindicators for future monitoring can be selected. The second phase of bioindicator selection, still in progress, is beyond the scope of this paper.

There are many papers that deal with the criteria or characteristics to use for bioindicator selection, and many more that describe the contaminants or radionuclides in particular organisms. Monitoring schemes will be most useful if they consider (1) many species representing different trophic levels (and groups within each level), (2) indicator selection based on sound quantitative data bases, and (3) caution in interpreting population trends, levels of anthropogenic stressors, contaminant levels, and other variables (Peakall, 1992; Burger and Gochfeld, 2001a; Carignan and Villard, 2001). However, the process of selecting species for a wide-ranging study of contaminants or radionuclides is not generally described. This paper addresses that issue for marine biota living around Amchitka Island.

2. Study Sites and Methods

2.1. Study Sites

Amchitka Island, in the western Aleutians (ca 51.5°N lat; 179°E long), and Kiska Island (about 120 km to the west (177.5°E Long) are part of the Alaska Maritime National Wildlife Refuge, bordered on the south by the North Pacific and on the north by the Bering Sea (Figure 1). The marine biological resources in the region are of high value in cultural, commercial, and ecological terms (NRC, 1996), and it is one of the most seismically active regions of the world (Jacob, 1984; Page *et al.*, 1991). Most of the Richter 7 quakes occur along the Pacific "rim of fire" which includes the Aleutian chain.

In World War II Amchitka was a military base opposing the Japanese occupation of Kiska Island. In the 1960s Amchitka was chosen for underground nuclear tests

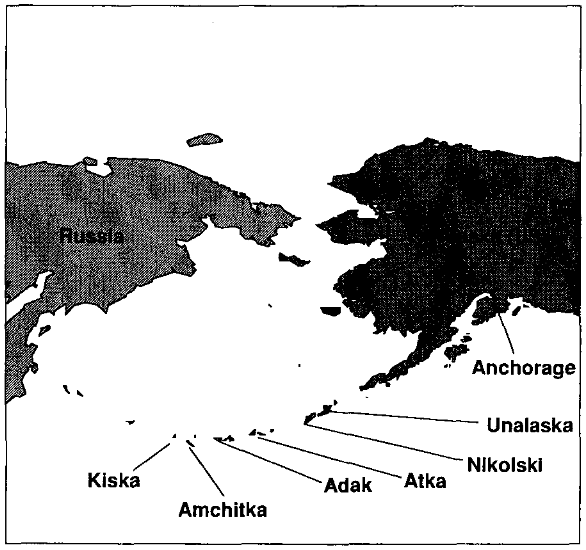

Figure 1. Map showing the location of Amchitka Island and Kiska Island in the Aleutian Chain of Alaska.

that were too large for the Nevada Test Site, despite the objections of local people and foreign governments (O'Neill, 1994; Kohlhoff, 2002). The remoteness of Amchitka, the tectonic activity (which might "hide" a nuclear test signature in seismic noise), and its proximity to the Soviet Union were key to its selection (Kohlhoff, 2002). There were three nuclear tests in 1965, 1969, and 1971. Cannikin (about 5 megatons in 1971) was the last and largest U. S. underground test. The blast affected the island coastline, and subsidence resulted in a depression lake on the island surface. The three Amchitka test shots accounted for about 16% of the total energy released from the U.S. underground testing program (Robbins, *et al.*, 1991; Norris and Arkin, 1998; DOE, 2000). Although there was some release of radiation to the surface, the leaks were not considered to pose serious health or ecological risks at the time (Seymour and Nelson, 1977; Faller and Farmer, 1998), and recent studies by Dasher *et al.* (2002) did not indicate any current surface contamination, although Greenpeace (1996) reported surface contamination. The three tests required an infrastructure on the island (buildings, roads, wells); in 2001 the DOE removed almost all structures and remediated most of the surface contamination.

The underground tests created large cavities, and the intense heat melted the rock, and trapped much of the radioactive material in a glass-like matrix. However, radionuclides were also distributed in the rubble-filled chimney, and the characteristics and permanence of the vitrified residuals are unknown. The relevant source term information is classified and unavailable to the public. As rainfall recharges the freshwater aquifer in the island's subsurface, radionuclides dissolved in the flowing groundwater could be carried through natural faults and fissures, eventually entering the sea (DOE, 2002a; CRESP, 2003). There is no current technology for remediating the test cavities or to inactivate or entrap the radiation.

Considerable concern on the part of the State of Alaska, the U.S. Fish & Wildlife Service, the Aleutian/Pribilof Island Association (APIA), and other stakeholders still existed when DOE announced plans to terminate its responsibility for the island. Public concern was substantiated by interpretations of the geology and geophysics of the area, which demonstrated the plausibility that radionuclides could be transported from the shot cavities to the ocean (Eichelberger *et al.*, 2002). The DOE's groundwater model predicted that breakthrough might occur any time from 10 to 1000 years after the blasts (DOE, 2002a).

2.2. Methods

Our overall protocol was to conduct a literature review of the most abundant biota that might be found around Amchitka Island, to place biota within a trophic level matrix, and to select from this species list those species to be collected for radionuclide analysis. This process is described in this paper to provide others with insights about how to select species for an ecosystem study that includes different trophic levels (and species groups within each level), with different niches and spatial locations represented (in this case, depths at which marine organisms live in the benthic environment), and stakeholder needs. The scientific names of species are given in Table IV.

Throughout the paper we assigned species to trophic levels, recognizing that early-life stages, and smaller individuals, may be at a lower level than larger, older individuals. The trophic level was assigned on the basis of adult status.

3. Results

The overall process we used to develop a list of species and groups within trophic levels for radionuclide analysis is shown in Table I. This process was used to arrive

TABLE I

Target Species Framework. Stages in selection of a suite of biota from which bioindicators of environmental contamination might ultimately be selected (depending upon chemical or radionuclide concentrations)

Step	Process
Identify interested and affected parties	*Identify the stakeholders with legal or agency mandates, those who are directly or indirectly affected, and those who are interested.
	*Identify mechanism for stakeholder involvement.
Literature review	*Review species present in ecosystem of interest
	*Review species used as bioindicators in the past for this or similar ecosystems
Expert review and advice	*Hold discussions with natural resource trustees and scientists having unique information about the species in that ecosystem.
	*Solicit resource trustee views on which species are of particular interest to them
Stakeholder review and advice	*Solicit views from interested and affected parties on the species of particular interest to them.
Select trophic levels for representation	*Consult with stakeholders above about trophic levels of particular interest
	*Decide on number of levels or nodes within trophic levels
Array possible species	*Array species in trophic levels.
	*Consider possible food web relationships where the top trophic level may not be a possible candidate for collection
Select organisms within trophic level for initial collection	*Include species whose locations or populations are amenable to collection
	*Include species of special interest to stakeholders listed above.
	*Consider three major groups: subsistence consumers, commercial fisheries, food web nodes (including ecosystem effects)
Include flexibility in form of ecological equivalents	*Recognize that in the field not all organisms might be amenable to collection.
	*Identify ecological equivalents that could serve the same trophic level function.

at the initial target species list presented in the approved and funded Science Plan (CRESP, 2003). The individual steps are described below.

3.1. Identification of affected and interested parties

Environmental monitoring and assessment does not occur in a vacuum, but is directed toward evaluation of a particular site or resource (species or habitat), with respect to a stressor of concern (either chemical/radiological, biological or other). Just as both the resource and the stressor require identification before the initiation of any aspects of a biomonitoring plan, the interested and affected parties must also be identified and there should be a consensus about the purpose of the monitoring program. We suggest that stakeholder identification is as critical to sound, public-policy driven research as is problem formulation. While it may be straight-forward to identify the resource managers and trustees responsible for the resource, as well as the appropriate regulators, it is less clear how to identify the primary public stakeholders.

For Amchitka, we used stakeholders to refer to any agency, group of people, or individuals that have an interest in the issues surrounding Amchitka. There were four major stakeholders that were all legally mandated to be involved in the process (Burger *et al.*, 2005). These included the State of Alaska Department of Environmental Conservation (ADEC), U.S. Fish & Wildlife Service (USFWS), Aleutian/Pribilof Island Association (A/PIA), and the Department of Energy (DOE). Each represented either agency interests or local residents, and each had direct interests in the information because it applied directly to their food supply (A/PIA, Alaska Department of Health and Social Services), or to natural resources they were responsible for managing (USFWS, ADEC)(CRESP, 2002). Other interested parties included environmental groups (such as Alaska Community Action on Toxics) and interested individuals. Bioindicators must be developed in such a way that they have long-term support, or they will not be conducted for a long enough time period to be useful (Stout, 1993; O'Connor and Dewling, 1986; Suter, 1990). This is especially true of long term stewardship at DOE sites where the needs for maintenance of residual radionuclides is projected for hundreds of years.

3.2. Features of bioindicators

In narrowing the preliminary list, the key features of useful biondicators must be considered. Managers selecting bioindicators often refer to the literature for an understanding of the characteristics used to select candidate species for bioindicators (Table II). Ideally the literature should be site specific. Indicators should be selected to maximize their biological, methodological and societal relevance (Table II). To be biologically relevant, an indicator must: (1) exhibit changes in response to a stressor (sensitivity), (2) the response should not be so sensitive

TABLE II
Features to use in selecting a target list of species for contaminant analysis

Biological relevance	* Provides early warning
	* Exhibits changes in response to stress
	* Changes can be measured
	* Intensity of changes relate to intensity of stressors
	* Change occurs when effect is real
	* Changes are biologically important and occur early enough to prevent catastrophic effects
	* Change can be attributed to a cause or a particular chemical
Methodological relevance	* Species common enough for collection
	* Species amenable to collection (e.g. eagles are not good candidates for largescale collection)
	* Species has a wide geographical and spatial distribution
	* Life history or trophic level known
	* Species could serve as representative of a given trophic level
	* Easy to use in the field
	* Can be used by non-specialists
	* Easy to analyze and interpret data
	* Measures what it is suppose to measure
	* Useful to test management questions
	* Can be used for hypothesis testing
	* Can be conducted in reasonable time
Societal relevance	* Of interest to the public and resource trustees
	* Of interest to native or subsistence populations, if relevant
	* Easily understood by the public
	* Methods transparent to the public
	* Interpretation transparent to the Public
	* Measures related to ecological Integrity
	* Cost-effective
	* Of interest to regulators and public policy makers

Once contaminant data are obtain for these species, bioindicators can be selected from this species list. Some of these characteristics are common to both the selection of the wide array of target species, and to final bioindicator selection (after Burger 1999, 2006; Burger and Gochfeld 2001a, 2004; Carignan and Villard 2002 and unpublished).

that it indicates trivial or biologically unimportant variations, (3) the changes must be attributable to a particular stressor (specificity), (4) the responses should be important to the reproduction and survival of the organism, and (5) the changes should be indicative of impairment to other species in the environment (Linthurst *et al.*, 1995; Burger, 2006). These same characteristics should be borne in mind when selecting a list of target species for chemical/radiological analysis.

While biological relevance is the key feature of a bioindicator, it must also be methodologically relevant (Burger and Gochfeld, 2001a, 2004; Table II). That is, a bioindicator should be easy for scientists to measure, for managers to use in their resource management, for regulators to employ in compliance mandates, and for public policy makers to apply to policy. Societal relevance is also an important attribute of a useful indicator – without such support it is unlikely that the indicator will be used over a wide enough spatial scale, and long enough temporal scale, to provide meaningful information (Fox, 1994). Society must be willing to both pay for the implementation of a biomonitoring plan (with specific indicators), and to act on the results.

3.3. Review of the Literature

The usual review of the literature for candidate selection involves determining what organisms are present in a given ecosystem, and subsequently comparing this list with species used elsewhere as bioindicators (Table I). This usually leads to the selection of top-level predators. In rare cases, there are data from the past on some species, and this increases the utility of these organisms as bioindicators. Historical data is often difficult to locate because it is in the gray literature; a range of stakeholders can aid in identifying and finding these reports. Faunal and floral lists of species from a particular area offer a starting point. Sometimes detailed ecological surveys with spatial data are available.

In the case of Amchitka, the literature review included information on species presence and abundance, trophic level and food-chain relationships, habitat use, and chemical/radiological work. We benefitted from the comprehensive volume by Merritt and Fuller (1977) that included many faunal papers with detailed species lists, often supplemented with biological accounts covering terrestrial and marine plants, invertebrates, fishes, mammals, and birds. In addition to the usual scientific literature, gray literature reports from resource trustees (State of Alaska, U.S. Fish & Wildlife Service), DOE, A/PIA, and conservation organizations were sought. We suggest that the literature review include both traditional/non-traditional sources, with particular attention to the stakeholder group reports and publications. Increasingly, it is possible to find faunal information on the web. The literature review for Amchitka resulted in an extensive list of potential species in a wide range of different taxa, from algae through marine birds and mammals.

3.4. Review by Experts

While a literature review can provide examples of the species available for bioindicators, scientists who work within a given ecosystem can provide first-hand experience about the organisms and their presence and abundance in the area of interest. Local biologists, both academic and resource trustees, as well as local naturalists, can provide recent data on species occurrence and abundance, critical or important food chains, or other interspecific relationships.

In the case of Amchitka Island, this involved discussions with marine biologists (including CRESP participants) who had worked in the Aleutians over the past 30 years, as well as in nearby Alaskan coastal ecosystems. The research experience of experts, qualified and updated the information available in the Merritt and Fuller (1977) volume, and a public/scientist/regulator workshop held to discuss Amchitka Island produced additional details (CRESP, 2002; Jewett, 2002). We had discussions with a range of biologists working for the USFWS, the National Oceanographic and Atmospheric Administration (NOAA), and ADEC who had worked on the marine resources of the Aleutians. We also had discussions with Aleut environmental officers. There was considerable overlap between the list of species suggested by other scientists and the one generated by the literature review.

3.5. Review by Stakeholders

Compiling a list of possible target species for collection and subsequent contaminant analysis should also include discussions with interested and affected parties. In many cases, such parties may have specific knowledge about the presence and distribution of organisms within that ecosystem. And of course, they will have particular species they are interested in, either because they are subsistence foods, are of medical or aesthetic interest, or are important to their lifestyle or world view. For example, salmon are of interest to many indigenous, subsistence and recreational cultures of the Northwest, and Bald Eagles are of interest to many Americans as a national symbol and to USFWS as an endangered species to be protected.

This phase includes not only stakeholders directly related to the ecosystem in question, but regulators and managers who have an interest in either specific organisms or food chains, but may not have technical expertise. That is, the public or resource managers may be interested in some top-level predators, but not be conversant with the total food webs supporting these species of interest. Moreover, recreational and tourism agencies have a special interest in environmental health and the services ecosystems can provide.

In the case of Amchitka Island, the initial input occurred at a public workshop on Amchitka Island held at the University of Alaska, Fairbanks (CRESP, 2002; Patrick, 2002). We also held discussions with people living in the Aleutians, and their views provided both a check on the species lists so far developed, added additional species of subsistence interest, and provided information on the relative difficulty of hunting/fishing for particular species. Ultimately, we visited Aleut villages to corroborate our target species list, rather than hold meetings only in Anchorage or by web-based communication. Although there was overlap between the Aleut lists and the literature/scientist lists, the Aleuts provided "relevance" information that helped pare down the larger list of target species.

3.6. Selection of Trophic Level Groups for Analysis

While many bioindicators described in the literature are top-level predators, or species that are high on the food chain, it seemed essential to develop a species list that was representative of different nodes on the food web because some studies make the assumption that top-level predators are the best bioaccumulators of contaminants. Other papers use plants as bioindicators, without ever providing comparative data on contaminants in other groups of organisms. By best accumulators, we mean the species that accumulate contaminants first, in high enough levels to detect and provide early warning. These assumptions particularly needed testing for a range of radionuclide isotopes.

Given the interests of managers, resource trustees, Aleuts, and other stakeholders, we identified the following trophic levels for representation at Amchitka: primary producers, grazers, filter feeders, low-level predators, intermediate predators, and top-level predators. The emphasis on predators was because they represented both intermediate steps in the food chain, as well as the ends, and were of interest to natural resource trustees, commercial fisheries, and Aleuts living on the islands. We also tried to select different species groups (e.g. birds, fish) within each trophic level, where possible.

3.7. Arraying of Possible Species Inclusion

The next step was to array all the species suggested as possible candidates for collection within the trophic level framework we had selected. This involved combining information from the literature and experts on trophic level status with species of interest to biologists, resource managers, Aleuts, and the public. This resulted in selecting several different organisms within each trophic level, allowing us to then apply relative abundance, spatial distribution, and other life history traits as additional criteria for target species selection (see below).

3.8. Selection of Species within Trophic Levels for Sampling

The final step was to review the array of species within each trophic level in light of the initial goals of the study (i.e. assessing food safety, understanding risk to marine organisms, selecting bioindicators for future biomonitoring). In this phase a number of other biological and logistical factors needed to be integrated for Amchitka, including relative abundance, size, distribution, habitat, depth, age, mobility, and lifestyle. Organisms had to be abundant enough to collect adjacent to all three test sites and the reference site, and had to be large enough to composite the requisite quantity for radionuclide analysis. For example, samples of 1000 g were needed for cesium-137 analysis, making it difficult to use fish eggs or small organisms. Similarly, it was essential to represent different habitats and niches, such as seabirds with local distributions and those with wider regional ranges. Seabirds were of particular interest because they nest on land where their eggs are accessible to humans, but obtain all their food from the nearby sea. Birds are subsistence foods of the Aleuts, are of interest to resource managers, and have been used extensively in the past as bioindicators (thus, comparative data exist, Thompson *et al.*, 1998; Burger and Gochfeld, 2001b; Cifuentes *et al.*, 2003).

For marine organisms, selection of species within trophic levels meant inclusion of organisms that lived in different tidal zones, and at different depths. This latter point was critical since it was not known where or at what depth any seepage of radionuclides into the marine environment might occur. Seepage could occur near land in the intertidal, or in the benthic zone at different distances from land (CRESP, 2003).

To illustrate these points for Amchitka, Table III lists some of the species selected for sampling, with the rationales associated with their selection. In most cases, species were selected that had at least two important features, such as key node on food chains, commercial fisheries, Aleut subsistence foods, or data existed in the literature for this species.

3.9. ON SITE ADJUSTMENTS

The final list of biota for collection at Amchitka and the reference site (Kiska) is shown in Table IV, as an example of the range of species selected for the radionuclide assessment from which bioindicators will ultimately be selected. The final collection list was modified in the field, due to abundance or lack thereof of certain species that necessitated some additions and some deletions from the list. This required an open mind at the beginning of the expedition, since it was not easy to determine on day 1 whether a particularly abundant species would be available at subsequent sites. Thus it should be noted that Table IV was a target list of species, and actual collecting conditions on the expedition were expected (and did) influence the final species list (Burger *et al.*, ms).

4. Discussion

Most papers in the literature either describe the criteria that should be used to select bioindicators, or they describe the use of one or two species as bioindicators (Burger and Gochfeld, 2001a, 2004). In the latter case, data on contaminants or radionuclides of interest are given, and the assertion is made that the organisms serve as a useful bioindicator because it accumulates the contaminant. While it may be true that the organisms accumulate radionuclides, there is no information to evaluate whether that organism is the best accumulator. That is, bioindicators should be among the first organisms to accumulate contaminants in sufficient quantities to detect (and that could, if high enough, be of significance biologically) because they can provide early warning. In this paper we suggest a process for arriving at a list of

TABLE III

Rationale for species selection for collection of biota for radionuclide analysis

PRIMARY PRODUCERS: The following species are all primary producers in the marine ecosystem, are sedentary (and thus represent local exposure), and are the base of some food chains. They have wide distribution in marine ecosystems. Some species are eaten by Aleuts and others. Intertidal organisms could be collected relatively easily by visiting biologists.

Alaria fistulosa – This kelp generally occurs <30 m in the benthic environment, representing the subtidal environment (requires diving for collection).

Alaria nana – This kelp occurs in the intertidal and shallow subtidal.

Fucus gardneri – This brown algae occurs in the intertidal, and there is reference data from other places for F. distichus, and from Amchitka. *Ulva fenestrata* – This green algae occurs in the intertidal, is eaten, and there is reference data from elsewhere.

GRAZERS: Invertebrates that consume primary producers are eaten by organisms higher on the food chain, and are fairly sedentary representing local exposure. Some grazers are also eaten by the Aleuts.

Green Sea Urchin – Urchins are abundant at different depths and thus could represent good coverage of the marine floor environment. They are a primary food of Sea Otters, a species of concern (and one that has declined precipitously in the Aleutian Islands). They graze on kelp, other algae, and microorganisms. Sea Urchins are also eaten by Eiders and Gulls (based on the literature), and they are considered a delicacy by Aleuts. Intertidal urchins could be collected from land, and are the ones that would be available to Aleut subsistence hunters.

Giant Chiton – Chitons are grazers that occur at deeper depths and could represent that benthic environment.

FILTER FEEDERS: Invertebrates that are filter feeders are also relatively low on the food chain, and occur at different depths. Some are eaten by Aleuts, as well as others.

Rock Jingle – They are less abundant than sea urchins, but are sedentary, and occur in the benthic environment. Diving required for collection.

Blue Mussels – Although they proved surprisingly uncommon at Amchitka, mussels have been used extensively as a bioindicator world-wide, and appear to be spreading into the far Aleutian islands. They are eaten extensively by many peoples, including Aleuts, and are intertidal in habitat, and so could be collected at low tide and from small boats.

LOWER PREDATORS: Still relatively low on the food chain, these organisms represent the middle of some food chains, are eaten by Aleuts, and some are commercial seafoods.

Rock Greenling – This is a sedentary species, each male maintaining a small territory, hence representing local exposure, lives in the kelp zone. It is eaten by Aleuts (as are its eggs), and is eaten by organisms higher on the trophic chain, such as Cod and Gulls.

Atka Mackerel – This is a pelagic fish that spawns on rocky substrates nearshore, and is relatively low on the food chain, but is of commercial value and is migratory.

Sculpin (Yellow Irish Lord) – This is a less sedentary (but not migratory) species, eats invertebrates, and is sometimes eaten by Aleuts.

Ocean Perch – Predator of pelagic invertebrates and forage fishes, relatively mobile and commercially important.

Eiders – Common Eiders are hunted extensively by Aleuts and their eggs are also eaten. It represents a low-trophic level for birds, since it eats mussels, snails, and urchins. It nests terrestrially (making it possible to collect easily) and feeds in the intertidal zone.

INTERMEDIATE TROPHIC LEVEL PREDATORS: These are generally abundant species, of especial interest to subsistence Aleuts. The fish are of commercial interest in the Bering Sea.

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TABLE III
(Continued)

Black Rockfish – This is a relatively sedentary species (representing local exposure) that lives in the kelp zone and just outside the kelp zone. It is eaten by Aleuts and is a little higher on the food chain than the Rock Greenling.
Gulls – Glaucous-winged Gull eggs are considered a delicacy by Aleuts, eggs are eaten, and gulls represent an omnivorous species. They eat urchins, sea stars, and fish (including Dolly Varden and Greenlings). Since there are nesting colonies at each of the test sites, and they normally feed within 5 miles of their colony, they represent local exposure. They do not migrate and so represent longer term exposure in the vicinity of Amchitka. They also can live to be 30 + years old.
Young Gull – There are nesting colonies adjacent to each of the 3 test shot areas, and on Kiska. Since parents feed their young entirely from local foods (usually within 5 miles of nesting colonies), they represent local exposure. Thus, chicks represent local exposure, from the previous few weeks, while adults represent longer-term exposure.
Tufted Puffin – They eat entirely fish of small to intermediate sizes. They are less localized to test shots, and represent exposure within a local area. They and their eggs are eaten by Aleuts.
Pigeon Guillemot – They eat mainly small fish and invertebrates, and are localized to the sides of islands during the breeding season.
TOP-TROPHIC LEVEL PREDATORS: At the top of the food chain, they represent the possibility for bioaccumulation. Many are long-lived, increasing the potential for bioaccumulation. Can be used as bioindicators for human exposure.
Octopus – Top-level predator within invertebrate food chains, can grow to considerable size that can live up to five years. Of special interest to Aleuts because it is a delicacy.
Walleye Pollock – This predatory fish is the major commercial species from the Bering Sea/North Pacific. They are mobile. Collected by trawling, rather than fishing near shore.
Pacific Cod – This fish can reach 50–60 pounds, and eats smaller fish, such as Rock Greenling and Atka Mackerel, as well as Octopus, squid, fish eggs, and crabs. It is both a preferred fish for the Aleut people and a major commercial species. It is mobile to migratory, moving from inshore to offshore.
Halibut – This fish is a top-level predator, can reach large sizes (up to 500 pounds) and advanced ages, and is highly prized both by Aleut and commercial fisheries, and is migratory.
Eagle – Top-level avian predator within marine ecosystems. Eats fairly large fish, and is of particular interest to U.S. Fish & Wildlife Service. Data on contaminants available for Amchitka.

These should serve as examples of the kinds of factors used to select species for chemical/radiological analysis of biota collected near Amchitka Island. While this list is not exhaustive of the target species list for the Amchitka Science Plan, it provides an indication of the types of parameters to use in species selection. Scientific names given in Table IV, except where no common name is available.

many species to be collected and screened for contaminant levels that will serve as the basis for bioindicator selection based on a trophic level approach. That is, we did not make the assumption that contaminants or radionuclides would accumulate in one taxon, one trophic level, or in one habitat, but designed a protocol for collection that would represent many trophic levels and habitats. We thus proposed a two-step process: (1) selection of a broad suite of potential bioindicators, with acquisition of contaminants information on all these species, and (2) selection of bioindicators from this suite. Both steps require extensive literature review, stakeholder input, and scientific evaluation. It is the first step that is described in this paper, and that is generally not performed in bioindicator selection.

TABLE IV
Species list for collection from the Amchitka Science Plan (CRESP 2003)

Species	Scientific names	Research vessel	Commercial fisheries	Aleut hunters and fishers
PRIMARY PRODUCERS				
Kelp	Alaria fistulosa, A. nana, Fucus	20 per species		
Sea Lettuce	Ulva fenestrata	20		
INVERTEBRATES				
Giant Chiton	Cryptochiton stelleri	20		
Green Sea Urchin	Strongylocentrotus polyacanthus	10		
Blue Mussel	Mytilus trossulus	10		
Basket Star	Gorgonocephalus caryl	5		
Rock Jingle	Pododesmus macroschisma	5		
King Crabs	Paralithodes camtschaticus, Lithodes aequispinus		25	
FISH				
Dusky Rockfish	Sebastes ciliatus			40
Pacific Ocean Perch	Sebastes alutus	40	10	
Salmon	Oncorhynchus spp.	where possible		
Dolly Varden	Salvelinus malma	20	40	
Atka Mackerel	Pleurogrammus monopterygius	20	40	
Rock Greenling	Hexagrammos lagocephalus			40
Walleye Pollock	Theragra chalcogramma		20	10
Pacific Cod	Gadus macrocephalus		60	60
Pacific Halibut	Hippoglossus stenolepis		60	20
Arrowtooth Founder	Atheresthes stomias		20	
Sculpin	Hemilepidotus spp.			20
BIRDS				
Common Eider	Somateria mollissima	20 (eggs)		20 (adults)
Glaucous-winged Gulls	Larus glaucescens	20 (eggs)		20 (eggs)
Bald Eagle	Haliaetus leucocephalus	15 (eggs)		
Tufted Puffin	Fratercula cirrhata			8
Pigeon Guillemot	Cepphus columba			8

(*Continued on next page*)

TABLE IV
(*Continued*)

Species	Scientific names	Research vessel	Commercial fisheries	Aleut hunters and fishers
MARINE MAMMALS				
Harbor Seal	Phoca vitulina			up to 10
Stellar Sea Lion	Eumetopias jubatus			up to 10
Sea Otter	Enhydra lutris			up to 10

The initial sampling plan called for a 40% collection effort by the scientists on a research ship, 20% by commercial fisheries, and 40% by Aleut hunters and fishers. Given are the targeted number of composites (5 individuals per composite). Some shifts in target species were expected after extensive stakeholder input (Burger *et al.* ms), and under field conditions.
Marine mammals were not collected as part of the expedition.

4.1. THE IMPORTANCE OF INCLUDING STAKEHOLDERS

Since the function of developing bioindicators is to assess health and well-being, status, and trends for species (including people), species groups, and ecosystems, it is useful to include the range of stakeholders that have an interest in the region, or are directly responsible for its management. Inclusion of a wide range of stakeholder inputs into the decisions about which species to sample means that the data will be more relevant to their needs. In this case, we include the responsible agency (DOE), regulatory agencies (US Fish & Wildlife Service, State of Alaska), subsistence Aleuts (A/PIA), and the general public. It is a public policy good to develop the best, most efficient, and most efficacious (in terms of early warning) monitoring system. Inclusion of stakeholders from the start is likely to result in a monitoring scheme that will be supported by the public and governmental agencies (PCCRAM, 1997). While we recognize that other studies have included stakeholders to varying degrees, we believe it should be an important process that is formalized, and occurs throughout indicator selection.

4.2. THE NEED FOR A BROAD SCALE EVALUATION OF SPECIES WITHIN ONE ECOSYSTEM BEFORE BIOINDICATOR SELECTION

The usual method of designing monitoring schemes goes directly from a literature review with expert input to selection of bioindicators, without a data analysis phase of contaminant assessment in a range of possible bioindicators. We believe this deficit results from two factors: (1) the large cost of undertaking an ecosystem screening study of contaminants in a particular site, and (2) the general acceptance of the assumption that top-level predators are the most useful bioindicators because they are the best accumulators of contaminants. This assumption is rarely tested, and is not examined with a range of chemicals or radionuclides. Yet, data on a range of biota is essential to selecting the best bioindicators for a site-specific monitoring plan. Indeed, our results for plutonium (Powers *et al.*, 2005) show that species at lower trophic levels are better indicators for this element.

It should be noted that assignment to trophic level is somewhat arbitrary in that we assigned trophic levels on the basis of the foods of adults (which we generally intended to collect), rather than on younger or smaller animals. We recognize, however, that a full description of trophic levels would assign small and very young fish to a different level that much larger fish of the same species. Our point, rather, is that scientists consider the inclusion of different trophic levels in their initial suite of species to evaluate as possible bioindicators. Merely assuming that top-level predators would be the best accumulators of all contaminants is just that – an assumption which requires testing, especially for radionuclides.

The DOE is faced with developing long-term stewardship plans for a number of its contaminated sites, especially those where residual radionuclides will exist for decades or centuries. Such is the case with Amchitka Island since there currently is no technology for cleaning up radionuclides residing in the underground nuclear test cavities. Biomonitoring thus becomes very important, and selecting the bioindicators is critical to biomonitoring. Further, it is essential to select the optimum bioindicators at the beginning of a monitoring program, rather than switching with time, or discovering at a latter date that a very different species (or group) is a better accumulator. Only by using the same biota as bioindicators over a long period of time can status and trends be determined.

4.3. Flexibility in Target Species List

The selection of a species list for a broad scale evaluation of contaminants, radionuclides in the case of Amchitka, represents compromises between a wide range of biological and societal factors. Biological factors include trophic level, size and abundance, and distribution (among others), and societal factors include subsistence and commercial foods, totems and aesthetic concerns, and resource management needs (e.g. information on declining species or their prey). However, managers and the public have to maintain certain flexibility that relates to availability in the field. Some species (such as salmon on Amchitka) may turn out to be less common or not amenable to collection methods. Further, life history traits may make sampling difficult. Salmon cannot scale most of Amchitka's streams, and there is annual variation in abundance (Valdez *et al.*, 1977). Likewise, the seasonality of sampling can influence the availability of specimens. In the case of Amchitka, salmon did not return to streams on Amchitka during our sampling, making it impossible to collect spawning salmon. Other species traits also impact the suitability of species for collection; birds lay eggs at particular times, and eggs are thus unavailable at other times of year. Further, octopus proved relatively rare at Amchitka, making broad-scale collection difficult.

4.4. Environmental Assessment and Public Policy Implications

The selection of bioindicators is the key process for developing any biomonitoring plan aimed at environmental assessment. Although it is clearly less costly in terms of time and money to select indicators *a priori* based on a literature review or expert judgement, we suggest that where long-term biomonitoring seems appropriate, a detailed assessment of chemicals or radionuclides in a suite of biota is essential before specific bioindicators can be selected. This will provide a data base of site-specific information on which to make sound selection decisions. This method has the advantage of being able to select biota which exhibit the best accumulator qualities within the ecosystem of interest. Early warning will be best provided by organisms which start to accumulate contaminants before others in the ecosystem.

Even with the method we advocate, there is still the possibility that a better accumulator might exist, but this likelihood has been lessened by a longer, more detailed process of selecting a rather wide list of target species, with actual analytical data on the contaminants of interest. Although the initial cost of this broad screen is larger than simply picking one or two species as bioindicators from a literature review (with expert input), it will maximize the potential for early warning within the ecosystem. Early warning will best be served by selecting one or two organisms that are the best bioaccumulators.

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